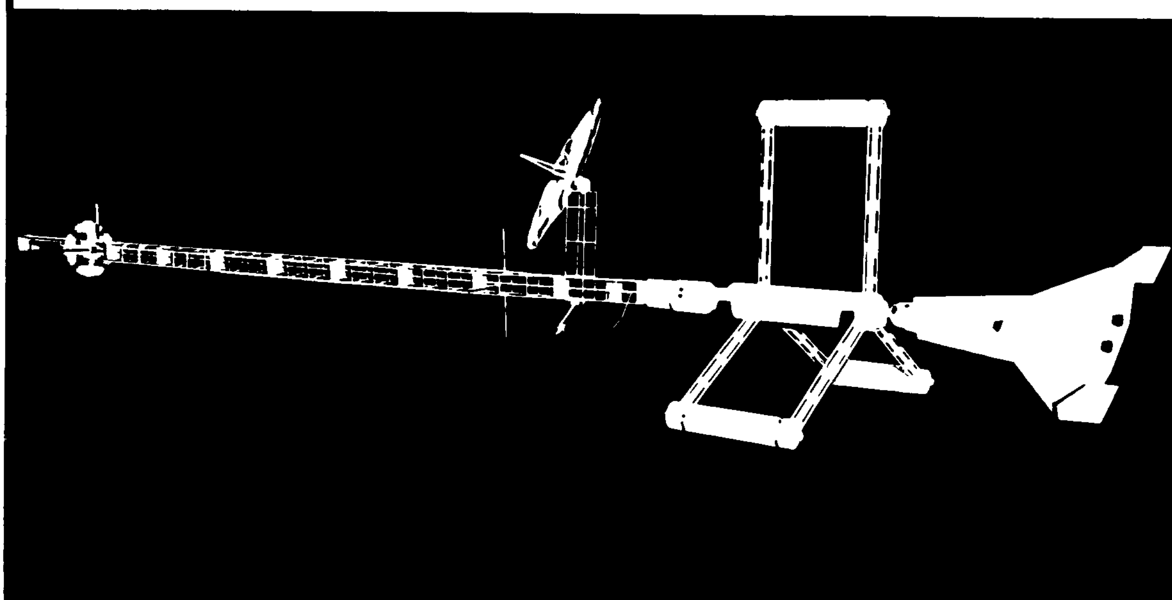
Second Annual Conference

NASA/UNIVERSITY ADVANCED SPACE DESIGN PROGRAM



Kennedy Space Center, Florida

June 18-20, 1986

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The NASA/University Advanced Space Design Program is operated by the Universities Space Research Association (USRA) under a training grant from NASA Headquarters (NGT 21-002-080). Inquiries regarding the program may be directed to the Project Administrator:

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Cover: Cover art depicts a model of the University of Michigan's Project Kepler, a nuclear-powered vehicle for the manned exploration of the martian system.

Introduction

The Program:

The NASA/University Advanced Space Design Program was conceived in the fall of 1984 as a pilot project to foster engineering design education in the universities and to supplement NASA's in house efforts in advanced missions. ("Advanced" was defined as being post Space Station Initial Operating Configuration.) Nine universities and five NASA centers participated in the first year of the pilot project. Close cooperation between the NASA centers and the universities, the careful selection of design topics, and the unbridled enthusiasm of the students resulted in a successful first year and the decision to extend the experiment to a second year. Nineteen universities (including the original nine) and eight NASA centers were involved in the second year's effort, the results of which are summarized herein.

The Conference:

The summer conference provides the opportunity for the universities to report on the results of their design projects. The oral reports are made by students (typically 3-4 per university) representing the design team (as many as 50-60 students) who worked on the project during the academic year. The presentations evoke considerable discussion, particularly among schools who may have taken somewhat different approaches to similar design topics.

Workshops comprised the other major portion of this year's conference. Organized along technology discipline lines (see page 23 for list), the workshops were an opportunity for the students, professors, and NASA representatives to discuss technology requirements to accommodate the advanced missions. The workshop groups met for two afternoon sessions and the chairmen (and women) summarized their findings on the final morning of the conference. No format was specified for these summaries and each group used whatever best fitted its story. These summaries are reproduced in the following pages.

Abstracts

A LUNAR TRANSPORTATION SYSTEM

Auburn University

Due to large amounts of oxygen required for space travel, a method of mining, transporting, and storing this oxygen in space would facilitate further space exploration. The following project deals specifically with the methods for transporting liquid oxygen from the lunar surface to the Lunar Orbit (LO) space station, and then to the Low Earth Orbit (LEO) space station.

Two vehicles have been designed for operation between LEO space station and LO space station. The first of these vehicles is an aerobraked design vehicle. The aerobraked Orbital Transfer Vehicle (OTV) is capable of transporting 5000 lbm of payload to LO while returning to LEO with 60,000 lbm of liquid oxygen, and thus meeting mission requirements. The second vehicle can deliver 18,000 lbm of payload to LO and is capable of bringing 60,000 lbm of liquid oxygen back to LEO.

A lunar landing vehicle has also been designed for operation between LO and the established moon base. This vehicle is capable of delivering some 20,000 lbm of payload to LO space station. This payload can be composed of all liquid oxygen or it may be a combination of liquid oxygen and other materials and equipment.

The use of an electromagnetic railgun as a method for launching the lunar lander has also been investigated. The feasibility of the railgun is doubtful at this time; however, future developments may make it a viable choice.

A system of spheres has also been designed for proper storing and transporting of the liquid oxygen. The system deals with spheres to be used primarily in returning the oxygen from the lunar surface to the LO space station, and then to LEO space station. The system assumes a safe means for transferring the liquid oxygen from tank to tank is operational.

A sophicated life support system has also been developed for both the OTV and the lunar lander. This system focuses on such factors as the vehicle environment, waste management, water requirements, food requirements, and oxygen requirements.

DESIGN OF A MARS ROVER

California Institute of Technology

This report summarizes the result of a ten week course devoted to the design of a 500 kg, 500 watt Mars rover. Its primary purposes are sample acquisition and study of the Martian terrain. Special consideration was given to autonomous systems to reduce the amount of Mars-Earth communication necessary during the mission.

The rover presented in the study is a 1.5 meter diameter, radially symmetric, six legged vehicle. The leg design employs a three-one-three system (three degrees of freedom at the hip, one at the knee and three at the ankle) to maximize the available three dimensional workspace of the foot. Power is supplied by radioisotope thermoelectric generators (RTG's) with batteries to provide additional power for operations such as drilling. A three-one-three manipulator, separate from the legs, is used to obtain soil samples and deploy instrument packages.

To keep the vehicle as autonomous as possible, the concept of a layered control system is advocated, each layer becoming more complex until the autonony of the rover cannot handle a situation and direct intervention by a human controller is necessary. Lower level control aided by tactile sensing includes foot and leg placement while the high level control focuses on modeling the surface and path planning. Laser ranging was chosen to create a depth map for the modeling and methods for autonomous operations using such models are outlined.

A ballistic hopper is presented as an alternative to the rover mission. The main advantage is that it is capable of long hops so a variety of terrains over the entire Martian surface can be studied. The hopper can be used as the sole mobility system or have a 500 kg rover included in its payload to provide more detailed surveying. A system to manufacture liquid propellant from the constituents in the atmosphere is outlined and first order calculations for performance are given.

Detailed design specifications and global system interactions are determined by simulations made from primary system components. Emphasis was placed on Mars-Earth communications, mission landings on the nominal Mars terrain and path determination within a model of typical interest areas on the Martian surface to produce statistical outputs based on these simulations. Besides simulation, feasibility and applicability studies are calculated for possible CAD software to be used in a detailed design of the rover. Recommendations concerning the use of this software are included in the report.

LUNAR FIBERGLASS: PROPERTIES AND PROCESS DESIGN

Clemson University

Presented by: Todd Nichols and William Dover

Several sources have discussed the properties and production of lunar fiberglass. The total cost of fiberglass produced on the Moon from lunar raw materials and used on the Moon and in low Earth orbit should be less than that of structural materials shipped from Earth. A design team at Clemson University undertook the specific task of designing a lunar fiberglass production process. A conceptual design was completed in the spring of 1986, and production of samples in a vacuum chamber is the goal at Johnson Space Center this summer.

Site selection was fairly straightforward. The highlands in general and the Apollo 16 site in particular meet the criteria. Regolith at the site is thick, homogeneous, fine-grained, and will fiberize. The area is also topographically suitable for a landing field and a mass driver. Lunar soil can be strip-mined with little or no processing and used directly as feedstock.

Two commercial fiberglass processes were considered: textile and spinnerette. The former involves pulling fibers through holes in a platinum bushing and winding them onto a spool. In the spinnerette process molten glass falls into a rapidly spinning disk. Fibers emerge from holes in the disk perimeter and fly in a curved path, much like cotton candy. The design team selected a modified spinnerette process due to frequent fiber breakage and labor problems with the textile process.

Since there is no lunar source of carbon for resin, a metal matrix was chosen. Metal-to-metal bonding in the vacuum will provide fiber adhesion. If the fibers are vapor coated with metal as they leave the disk, they can be collected on rollers and pressed into sheets. These sheets can be rolled into tubing or layered into plywood-like panels. A final coating will prevent gas adsorption and adhesion to other surfaces.

This summer's objective is to make a sample of calcium-matrix fiberglass from regolith simulant. A quick and simple one-fiber textile process will be used. A silica glass melting pot heated by six glowbars inside a radiation shield will provide the fiber. A reel with six bars will take up the fiberglass while a vapor source coats the fiber with calcium. A lead screw will move the reel back and forth to form layers. Six samples will be formed in one run. The entire apparatus will be in a vacuum chamber. Materials tests will be made on the samples, and thin sections will be cut from them.

The summer's results will yield data needed to decide if the composite has useful structural properties, to optimize the fiber-to-matrix ratio, and to refine the conceptual design of a spinnerette system. The next step would be construction and testing of a spinnerette prototype, followed by final design of a lunar fiberglass plant.

2010: A CONCEPTUAL DESIGN FOR A MANNED, ROTATING, GEOSYNCHRONOUS SPACE STATION

University of Colorado, Boulder
Presented by: Gretchen Conley, Aurand Jones, Johan Morris, Susan Rose

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The design of a permanently manned geosynchronous space habitat (GSH), to be operational in 2010, poses a unique design challenge. New technologies mandated for the development of GSH include structures, shielding, power, control systems, life support systems, and controlled ecological life support system (CELSS). These subsystems can be applied to all future space missions.

One of the most beneficial services performed through GSH is satellite repair. There are currently over 250 satellites in geosynchronous orbit. Approximately one third of these satellites are inactive or in an incorrect orbit. Many of these satellites can be made operational by resupplying attitude control propellant. As the average operational lifespan of a satellite is seven to ten years, by 2010 virtually all current satellites will be inoperative. GSH can be used as a central base through which satellite repairs and services can be performed, therefore, increasing the cost effectiveness of the satellites in geosynchronous orbit. The cost to reach disabled satellites from geosynchronous orbit is five times more fuel efficient than that from a low earth orbit.

One of the long term applications of GSH is that of a testing site for new technologies. For example, the proposed design incorporates the use of plasma shielding to protect GSH from radiation. A weight savings of 98% over bulk shielding and 95% over conventional magnetic shielding will be achieved. By using the GSH as a research environment, this and other technologies can be tested, researched, and then utilized with greater assurance in future space missions.

The proposed station is permanently manned. The initial and operating costs of a manned station are increased due to life support and safety considerations. However, mission flexibility and station repair can be increased by man's ingenuity, flexibility, and adaptability.

Much of the design of GSH has been driven by man's presence onboard. Physical and mental health of the crew are necessary for the station's success. Micro-gravity has many adverse effects on the human physiology. It is estimated that the acute effects of zero gravity on human physiology such as loss of bone calcium, loss and redistribution of body fluids, Space Adaptation Syndrome, and coordination losses result in a 25% loss of productivity of the mission. Two to three hours per person per day of exercise is required to prevent the long term effects of micro-gravity. Nine hours of productive time per day are lost due to the micro-gravity environment. To eliminate the effects of the micro-gravity environment as well as to increase productivity, GSH will be rotated to induce an artificial gravity of 0.8 g.

The basic design of the proposed space station is relatively simple. There are eight habitation modules in which nearly all activity will be performed. These modules are arranged in a torus with a radius of thirty meters. Central storage, repair, and docking facilities are located on the axis of rotation of the torus. The docking and repair facilities are able to despin, decoupling from the rotating station allowing access by approaching vehicles. There are four access arms from the torus to the axis of rotation. The estimated total weight and volume of the station are 150 metric tons and 4400 cubic meters respectively.

The power for the station will be supplied by two free flying solar arrays with a backup system of onboard fuel cells. The power required to maintain minimal life support and shielding is approximately 50 kilowatts. When the station is fully operational a maximum of 250 kilowatts are required. Miniature Cassegrainian collectors coupled with multi-band-gap cells constitute the means of solar energy collection. The efficiency of the system should be approximately 68%. Each free flying array is capable of producing the desired 250 kilowatts.

The control system of GSH consists of hierarchically linked networks of distributed controllers. This system simplifies reconfiguration and upgrading while providing a high degree of fault tolerability. The control system of GSH are also highly modular making them adaptable to varying missions.

Life support is a critical issue. The operational guidelines necessary to sustain human life are outlined and investigated with appropriate envelopes of acceptability. From these guidelines, specific systems were determined for life support, such as atmospheric gas monitoring, use, and storage.

A controlled ecological life support system, a bioregenerative system, is also included in the design of GSH. GSH will be a 97% closed system, receiving only minimal supplies from earth. As much as $455 million can be saved over a fifteen year period by using this closed system. The CELSS is incorporated into the life support as a means of producing and processing foods as well as a means of producing oxygen and cleansing the environment.

The proposed permanently manned geosynchronous space station attempts to minimize cost while optimizing mission effectiveness. The necessary subsystems have been defined and examined. The end result is a feasible design from which present technologies will beneift and innovative technologies will develop.

DESIGN OF REGENERATIVE SYSTEMS FOR GROWING HIGHER PLANTS IN SPACE

University of Florida

During the academic year 1985/86 the EGM 4000/4001 Engineering Design course at the University of Florida was conducted in cooperation with personnel from the Controlled Environmental Life Support System (CELSS) Program of NASA/KSC. This course is generally taught to a multidisciplinary group of approximately 20 students, is project oriented and serves as the capstone senior course for Engineering Science majors. The course seeks to give seniors a working knowledge of engineering design principles and techniques through participation in a number of projects, usually including one major theme project plus a number of small, limited purpose projects. In addition to the standard design subjects, students are given considerable experience at project organization, project management, oral presentations and technical report writing.

The theme project for the 1985/86 year was the design of a regenerative system for growing higher plants in space, a critical part of the NASA/CELSS program. Close cooperation with NASA personnel was maintained through a combination of regular visits and frequent telephone contact. The first semester focus was on overall system design. This work dealt primarily with issues of plant biology and pathology, geometric configuration, structural design, plant physical support, plant spacing, nutrient delivery, lighting, atmospheric composition, plant propagation and human involvement. The result was two alternative designs, one centered on an aeroelectroponic nutrient delivery system and the other on a liquid nutrient delivery system.

The second semester the class was divided into four independent design teams and sought to design, fabricate and test prototype components identified as critical needs during the first semester. These projects involved • an expert system for detection of soybean diseases, • A variable gradient dehumidification and water retrieval system, • an electroponics nutrient delivery system, and • plant support structures for a microgravity plant growth chamber. This work developed and tested several novel ideas of practical importance to the CELSS program.

Overall, the 1985/86 academic year program has been an outstanding learning experience for the students in the Engineering Design course and has produced new concepts of potentially significant value to an important NASA project; this program thus is judged to have been clearly successful and a highly worthwhile investment of resources.

LUNAR MINING DEVICES & OTHER STUDIES

Georgia Institute of Technology

Georgia Tech's participation in the NASA/university advanced space design project for the 1985-86 academic year has been centered in the George W. Woodruff School of Mechanical Engineering. The program has as its core course ME 4182, mechanical design engineering. This course (or its alternative, ME 4317, thermal systems design) is the required senior design project course for undergraduate mechanical engineering students. The ME 4901 special problems course is the design elective used by the undergraduate mechanical engineering students to extend their design project following ME 4182. Students from other disciplines participating in the program function as design team members in ME 4182, but receive credit for ME 4901 or courses offered by their respective schools. The aerospace engineering, ceramics engineering, and electrical engineering students that participated during this academic year made significant contributions to the designs. Each of these courses represents 3 quarter hours. At the graduate level, the ME 8501 special problems course is used to focus the graduate student's participation in the program. This system design course provided a lunar base concept from which a number of unified design problem statements were identified for the seniors. During the academic year, a total of 134 students participated in the program.

The conference presentation will provide an overview of the topic area pursued during the year and describe a few of the 20 design projects. The design projects centered about the theme of initial lunar construction and manufacturing of materials from the lunar soil. Our plans for the next few years will be discussed along with the recently established engineering college design laboratory. This was brought about by the combined work of the key faculty members associated with this project, Mr. James W. Brazell and Dr. Wendell M. Williams, Jr. Assisting them for the academic year was Gary McMurray. Mr. Frank Swalley, of Marshall Space Flight Center, served as our host center representative and Mr. Barney Roberts of Johnson Space Center attended our spring quarter presentations. The ME 4182 design projects chosen by the students were:

Fall quarter
Space vehicle shield
Mobile lunar strip mining for oxygen
Manufacturing of lunar bricks
Space shuttle fuel tank reclamation
Lunar freight lander
Lunar electrical power station
Space adaptation trainer
Winter quarter
Lunar material benefication for aerobrake construction
Structural materials for lunar shelters
Lunar surface/orbit cargo transport vehicle
Ten meter lunar drill
One hundred meter lunar drill
Lunar material transport vehicle
Lunar mining system
Ten meter martian drilling system
Spring quarter
Transportable 100 meter multi-purpose lunar drill
Soil-engagement excavator implemant
Structural element manufacturing
Lunar bricks
Self-propelled utility crane for the lunar environment
Lifting and transport vehicle for lunar applications

LUNAR OXYGEN TRANSPORTATION SYSTEM

University of Illinois, Urbana/Champaign
Presented by: Raymound A. French, Stephen F. Heinz, Major D. Murray, Ensign, USN, Joseph Santos, Roberto L. Vasquez

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Aeronautical and Astronautical Engineering 241 is a senior-level, aerospace vehicle design course at the University of Illinois, Urbana/Champaign campus. The course is offered only in the spring semester and the enrollment in the spacecraft design section averages around 50 students. They are normally divided into six or seven design teams. This spring, the class was divided into two competing design teams because of the scope of the design project.

The design project, a Lunar Oxygen Transportation System (LOTS), had the objective of supplying lunar liquid oxygen (LLOX) to the space station (SS) in low Earth orbit (LEO). The performance specification was to transport sufficient LLOX to support 10 to 15 LEO-to-geosynchronous-orbit transfers, using approximately 60K lbs of LOX per transfer. The driving factor was low cost such that LLOX delivered to LEO was more economical than LOX delivered from the Earth's surface.

The components of LOTS were constrained to be (1) a lunar transfer vehicle (LTV) for ferrying between the lunar surface and a space station (LSS) in lunar orbit, (2) the LSS acting as a transfer node and a storage depot, and (3) an orbital transfer vehicle (OTV) capable of attaining lunar orbit and using aerobraking on return to LEO. Propulsion systems were constrained to use advanced expander cycle engines using LOX/LH2 in a 6:1 ratio. Assumed to exist were a lunar base with a mining and oxygen manufacturing facility located on the equator and facing Earth and a SS in LEO with a 270 nmi altitude and a 28.5° inclination.

Each design group was divided into three subgroups, one for each vehicle. The subsystems examined by each subgroup included orbits, propulsion, structures and mechanisms, power and communications, thermal protection, systems and cost.

Only one of the final designs is presented in detail. To summarize that system's design, an Apollo derived LTV ferries 70K lbs of LLOX per trip to the LSS for storage. The LOX is transferred between vehicles by pressure gradients into structurally integral tanks. The LSS, a derivative of the proposed SS power tower configuration, is in a low equatorial circular lunar orbit, is solar powered and has a truss structure. After four LTV trips, an OTV arrives to load approximately 280K lbs. The OTV uses a total of 220 lbs of LOX per round trip, leaving a net of 60K lbs delivered to LEO on each trip. Thirteen trips are needed each year to deliver 780 K lbs of LOX to LEO. The major difference between the two designs is that the second uses tank transfer to move the LOX.

The major problem encountered in making the system economical was using Earth derived liquid hydrogen (LH_2). If the moon could become a source of (LH_2) then the system could easily become economical. A benefit of LOTS not directly related to oxygen transfer is the capability of the OTV to transfer 15K lbs cargo to the moon per trip or 195K lbs per year. Such considerations may make such a system beneficial until improvements can make the system economical.

MOBILE REMOTE MANIPULATOR SYSTEM

University of Maryland

In this talk we give a progress report on the advanced design project at the University of Maryland. The goal of the project was to design a mobile remote manipulator system (MRMS) for the Space Station. We have carried out a top-down design exercise starting from the basic specifications for the MRMS as presented in the Space Station Reference Configuration document and other more recent published works including revised requirements.

The selection of a kinematic design was followed by a sizing study of the actuators, gear trains, and links for two different specifications, one for a 50 foot reach arm and one for a 100 foot reach arm. The greater reach requirement arose from an early March report indicating the need for the capability to dock the shuttle with the assistance of the MRMS.

The project team studied the problem of navigating the MRMS on the keel of the Space Station while avoiding obstacles (modules) near the keel. This led to an algorithm that was extensively tested in simulation. The design of the servo-controllers for the joint actuators was an important task for the project team and this was accomplished with the assistance of software developed at the University of Maryland.

An important part of this project was to develop a graphical animation test-bed for the design ideas developed during the course of the project. Currently we have such a simulation running on an Iris graphics workstation that communicates with control processes operating on other machines.

The entire project was carred out during the Spring semester of 1986 and we plan to make refinement of the current design during the summer.

Project Team: Xin Chem, Thomas Posbergh (graduate assistant), Alan Ruberg, Reza Shahidi, Eunsip Sim, Arvind (Velu) Sinha, N. Sreenath, Randall Winchester, Li Sheng Want, Jia-Chang Wang, Rui Yang.

Project Director: Professor Krishnaprasad, Electrical Engineering Department, University of Maryland.

Associated Faculty: Professor Lung-Wen Tsai, Mechanical Engineering Department, University of Maryland.

MARS EXPLORATION MISSIONS

Massachusetts Institute of Technology

The primary objectives of the National Aeronautics and Space Administration are the scientific study of the universe, the exploration of our solar system, and the encouragement of space enterprise. With the construction and use of space stations orbiting the Earth and the beginnings of further development of our moon, the investigation and eventual habitation of Mars is a logical and feasible step in the pursuit of these objectives.

The 1986 Space Systems Engineering class of the Massachusetts Institute of Technology has developed a plan for the comprehensive study of Mars and its moons. This program is planned for the years 1990 to 2010 and consists of two phases: the unmanned Exploratory Mission and the Manned Mission. This program for the exploration of Mars adopts NASA's objectives as its primary goals.

The Exploratory phase of the Mars mission paves the way for future missions, collecting information vital to the establishment of a manned surface base, as well as scientific data for the better understanding of Mars, its history, and its environment. This phase will examine possible base sites with regard to surface features, meteorological, magnetic and seismic environment, and composition. The moons of Mars, Phobos and Deimos, will also be visited. These objectives will be accomplished over the course of four years by 43 vehicles including autonomous rovers, atmospheric survey vehicles, and spacecraft. Samples collected from the surface atmosphere and moons of Mars will be returned to Earth for study.

The culmination of this program is a ten person Manned Mission which includes a 290-day stay on the surface of Mars. A base will be constructed to provide a semipermanent habitat which can be used for future Mars missions. A mobile laboratory gives the crews the opportunity to make extended forays from the base. The manned presence will expand our knowledge far beyond that provided by the unmanned Exploratory Mission and allow for the developoment and utilization of Martian resources.

Costs for the entire program are estimated at 42 billion dollars. For the purpose of the study, no budget or ceiling was set for the total cost of the program. Therefore, the design criteria focused on feasibility rather than cost effectiveness. As the Manned Mission costs are roughly ten times that of the Exploratory Mission, further studies should examine the optimal use of autonomous and manned equipment to meet the program goals. In addition, further research is needed in artificial intelligence, electric propulsion, life support systems, and human physiology in reduced gravity environments.

PROJECT KEPLER

University of Michigan
Ann Chopra, William Emanuelsen, Joseph Heibel

Transporting personnel to Mars for a manned landing and exploration is a major undertaking. To carry out this mission, an efficient and reliable transportation system is required. Advances in the technology areas of electric propulsion, nuclear electric power, thermal management, and control of large space structures will have to take place before such a mission is possible. The human problems of long-duration manned space flight will also have to be addressed to insure the wellbeing of the crew. Project Kepler is a study and preliminary design of the transfer vehicle required for a manned Mars mission.

The Kepler Mars Transfer Vehicle (MTV) utilizes low-thrust; mercury-ion thrusters powered by an 11 MWe nuclear reactor to transport a crew of seven to Mars and return. A liquid droplet radiator (LDR) is used for power system thermal management. By spinning the living modules, artificial gravity equivalent to that at Mars is continually provided for the crew, thus alleviating the problems caused by long-term exposure to a zero-gravity environment. Four of the crew will land on Mars utilizing a high lift-to-drag ratio lander vehicle. Total trip-time for mission is 573 days.

Many new and emerging technologies were studied and integrated into the design of a functional and technically feasible vehicle for the transport of men and equipment to Mars in the early 21st century.

SPACE STATIONS AND TRANSPORTATION SYSTEMS

United States Naval Academy

During the 1985-86 academic year, 15 first classmen in the Spacecraft Vehicle Design course in the Aerospace Engineering Department participated in the NASA/USRA Advanced Space Design Pilot Program. They were divided into three groups, each of which participated strongly in the selection of its project. The projects selected were an earth-moon transportation system, a space construction and repair facility, and a space-based moon ore capture system and manufacturing plant.

During the year, these three groups met weekly (at least) with a group of four faculty including two senior staff members from the Goddard Spaceflight Center (GSFC). Each group laid out a plan for the accomplishment of its task and reported each week on its progress, showing completion of both long-term and short-term milestones, problem areas, etc. During the course of the work there were a number of visits by the midshipmen to the GSFC for consultations with GSFC staff. At the end of the semester, each group submitted a complete report and made an oral presentation on its work. The reports and presentations were judged by the faculty involved with the course plus several other members of the department in an informal competition. The winners of the competition will make the major presentation for the Academy at the KSC Advanced Space Design Program conference. The winning project was the earth-moon transportation system. Abstracts for the three projects are given below.

GEOSEL: AN EARTH-MOON TRANSPORTATION SYSTEM

In order to meet the requirement of logistically supporting planned lunar activities a reusable three component transport system that moves various payloads from low earth orbit to the moon's surface is proposed. The system consists of cargo containers, a trans-orbital tug that transports four payload containers from an earth parking orbit to a similar orbit about the moon, and a lander that brings the containers to the lunar surface one at a time.

The first system requirement is shuttle compatibility. Since the containers are to be brought into orbit by the STS, their maximum weight and size as well as mounting pins were fixed by the shuttle. No further design aspects of the container were considered outside of these three parameters. The second component of the system, the tug, is the heart of the system and was the focus of the design effort. The energy needed to transfer four containers to lunar orbit caused a considerable change from the original concept of the tug. The high energy requirement dictated that the tug fuel tanks be prohibitively large. The redesign of the spacecraft showed that by staging the vehicle the tankage problem could be solved. The propulsion and tankage requirements, the structual demands, and a detailed weight estimate were the major design aspects given the most detail in the tug design. Other tug components, such as the crew and power module, attitude control system, and communications systems were taken either from existing or proposed spacecraft designs. Two major components taken directly from the space shuttle are the four SSME's used to propel the tug, and the shuttle's remote manipulator arm that will be used to transfer the payloads from the tug to the lander while in lunar orbit

As far as the lander is concerned, time constraints did not allow for more than a preliminary design overview. Initial weight, thrust, and tankage estimates were made. From these, a drawing was made of a possible configuration for the lander.

SPACE CONSTRUCTION AND REPAIR FACILITY

This project produced a space system capable of performing construction, maintenance, and repair on present and future satellites and on space vehicles. The design includes all the basic elements of space structures, such as power, thermal control, attitude determination and control, orbital maintenance, and communications, in addition to the mission specific requirements. Emphasis is placed on modularity, expandability, and compatibility with the Space Station.

The "Space Hanger" is 58m by 42m by 26m in size and will weigh 149,000 kg. The facility has mobile restraint stands, portable test equipment, and a pressurized workshop area. It would go into a 431 km circular orbit. The total system cost, including shuttle ferry missions is estimated to be $8.58 billion. The system will require 18 dedicated shuttle missions to be placed in orbit.

SPACE BASED MOON ORE CAPTURE SYSTEM AND MANUFACTURING PLANT

A magnetic rail launcher on the surface of the moon is used to launch chunks of ore from the lunar surface toward the earth. Their trajectories must pass through the lower earth's atmosphere to proivide the needed atmospheric drag to slow the ore modules sufficiently so that they can be interecepted by the capture system. After the ore has been captured, it is transferred to a manufacturing plant in a near earth orbit. The primary design concerns of the project were the moon ore catcher and the power system for the manufacturing plant.

MANNED MARS MISSION

North Carolina State University

A scenario for a manned expedition to Mars was studied by the North Carolina State University senior design class in conjunction with NASA-Langley Research Center. Current and near future technology was considered in developing a system for transporting a crew to Mars, establishing a human presence, i.e., a Mars surface base and orbiting station, and safely returning the crew to Earth. The main design philosophy was to allow for all vital supplies to be in place and operational at Mars before personnel are sent.

Several assumptions were made in order to increase the mission feasibility. A permanent Earth-orbiting station will be needed to provide a facility for components assembly. A lunar mining capability will also be needed. By using lunar resources and by building spacecraft in lunar orbit, Earth dependence and fuel costs are greatly reduced. A heavy lift capability to Earth orbit will be required for transporting large quantities of resources, primarily liquid hydrogen. Liquid hydrogen is necessary for propulsion and is not found on the lunar surface. A first generation nuclear rocket is needed. Present day rocket fuel requirements are prohibitive. The nuclear rocket allows for reasonable mission times (1-2 years) with significant fuel savings. The technology to control rotating flexible structures is also required.

The scenario requires the design of five major components: a cargo craft, an insertion assist vehicle, a personnel transport vehicle, a Mars orbiting station, and a Mars lander. The Mars orbiting station consists of a hub containing docking bays for the Mars lander and orbital transfer vehicles. The station has two arms; one contains habitation and laboratory modules and the other holds the station's power plant. The station rotates about its hub, creating centripetal acceleration so that one-third Earth's gravity is induced in the modules. The station is constructed in lunar orbit and boosted into a Martian trajectory by multiple insertion assist vehicles. Additional propulsion is provided by low thrust ion engines. They transport all necessary provisions, material, and fuel for the construction of a Martian base and the safe return of the personnel transport vehicle to Earth. The crafts are constructed and loaded in lunar orbit and utilize the same propulsive systems as the Mars orbiting station in their transit to Mars.

Following the successful arrival of the Mars orbiting station and slowboats in Martian orbit, the personnel transport vehicle and crew will be launched on a rapid trip (less than 200 days) from low Earth orbit. The personnel transport vehicle will be constructed in Earth orbit and will produce an artificial gravity environment of 1-g by rotating habitation and laboratory modules. The personnel transport vehicle uses a first generation, hydrogen-fed, nuclear rocket engine. Following insertion of the personnel transport vehicle into Martian orbit, and rendezvous with the waiting Mars orbiting station and slowboats, the exploration crew is transferred to the station to begin preparation for the Mars landings. During a sixty day exploration period, a permanent Martian base and automated mining facilities are established. The personnel transport vehicle is then refueled with the liquid hydrogen stored aboard the slowboats for the return trip to Earth.

The orbiting station and surface base represent a human presence on Mars. Future missions will expand on this accomplishment. In summary, this scenario provides the infrastructure for future space explorations.

MARS SURFACE-BASED FACTORY; PHASE I. A CONCEPTUAL DESIGN

Prairie View A&M University
Presented by: Alfred Dawson, Frank Hayes, Michael Malone, and Byron Williams

In any manned mission to Mars, a large portion of the payload will consist of life-support products and technology-support products (e.g., propellant). It is important that every effort be made to investigate the feasibility of setting up a factory for the manufacture and storage of these products using materials on the planet and its moons. The products of interest are oxygen, water, hydrogen and methane.

The Design Group at Prairie View has made a detailed study of the surface and atmospheric composition of Mars. Studies have also been made of various manufacturing techniques of these products. Analysis has been made to determine which of the current production methods are adaptable to the Martian environment.

The necessity to design drilling equipment for use in the positive identification of large quantities of water, believed to be underground, will be demonstrated. Oxygen and hydrogen are the best combinations for fuel, with water and carbon dioxide as the raw materials.

Based on the initial studies, the Design Group has determined oxygen and water to be the two products that could be produced with the Martian conditions. Some of the preliminary ideas associated with the conceptual design of the factory will also be presented.

Most of the preliminary studies have been completed and the group is currently concerned with the conceptual design of the various components of a compact automated factory for the manufacture of one of the two final products. Regardless of the product to be manufactured, the space factory design for different products will have some commonality. Based on this similarity, the stucture of the factory design will include: (1) thermo-chemical process definition; (2) automatic and logic control, and power source definition; (3) system and process analysis, and implementation; (4) computer-aided design and manufacturing; and (5) definition of the factory's function, requirements, mobility, stability, limitations, and reliability.

MANNED MARS MISSION

Texas A&M University

Texas A&M University has had two academic departments, Aerospace Engineering and Nuclear Engineering, participating in the USRA pilot project. Texas A&M has worked as part of a team with the University of Texas at Austin in investigating various components and scenarios for a Manned Mars Mission, with a bias toward consideration of long term permanent operations. The A&M teams have concentrated on the interplanetary trajectory, the interplanetary vehicle, propulsion and power for the interplanetary vehicle, and power for the Mars base.

In the fall semester of 1985, the Aerospace Engineering design group at Texas A&M University studied several topics related to the design of a Manned Mars Mission interplanetary transfer vehicle. Among these were propulsion systems, low thrust and impulsive trajectories, human factors, radiation shielding and vehicle configuration. The propulsion systems studied were chemical, nuclear thermal, and nuclear electric. The trajectory group studied missions for the period 2005 to 2015 AD and developed codes to find Earth/Mars positions for a given transfer time and constant-thrust trajectory, and a minimum-mass algorithm. The human factors study concentrated on the psychological aspects involved in a long duration mission in close quarters and isolation. The radiation shielding study briefly examined magnetic shielding and produced a design method for passive shielding that yielded a multilayered shield providing acceptable internal radiation dosage levels. Finally, a preliminary transfer vehicle concept was developed to provide artificial gravity of 0.7-g's by rotation for a crew of six and a mission duration of 650 days.

In the Spring of 1986 the A&M Aero group produced a conceptual design for the interplanetary transfer vehicle based on specifications and requirements determined in the previous two semesters. The assumptions for this design were that the ship would provide a 1-g environment for a crew of six and would use a nuclear electric propulsion system. For this design it was determined that the entire vehicle would be rotated at 3 rpm to produce the artificial gravity in the space station-derived habitation modules. The payload is arranged in a single plane and is symmetrically distributed about the center of mass. Components that were researched included a mechanical environmental control and life support system (ECLSS), a "safe-haven" radiation shielding system for use during solar flares, a personnel transportation system (PTS), a liquid droplet radiator (LDR) system for waste heat rejection, and a solar dynamic backup power system.

Several space related design topics were studied during the past year by the Texas A&M Nuclear Engineering Department. Projects in conjunction with the second year of the USRA pilot program concentrated on nuclear power and propulsion systems for surface bases, space stations, and spacecraft. A Mars base power supply system, intended to be the primary source of power for a permanent base involved in industrial activity, was the subject of three successive projects. The requirement of 5MWe for ten years was met by a liquid-metal-cooled fast reactor, utilizing UO_2 fuel and NaK coolant. Also, a compact space reactor for remote space applications was studied. The near absence of moving parts in such a system increases the reliability for long duration missions.

Several different power/propulsion concepts for a Manned Mars Mission were also investigated. Among these were nuclear electric, nuclear direct thrust, and scoping calculations for a fusion plasma propulsion system.

MANNED MARS MISSION

University of Texas at Austin

Teams of Aerospace Engineering students from the University of Texas at Austin have carried out designs related to the Manned Mars Mission over the three semesters of the pilot project. The UT teams have carried out projects which complement those of the teams at Texas A&M, with UT concentrating on operations at Mars including descent/ascent vehicles and Martian moon exploration.

During the Fall of 1985 and Spring 1986 semesters at the University of Texas at Austin, two different Ascent/Descent vehicles were developed. Several configurations were considered including shuttle-derived lifting bodies, bent biconics, raked cones, and Apollo-derived capsules. During the first semester, a single-stage bent biconic configuration was chosen based on the established vehicle requirements, with emphasis on a crossrange capability of 200 km and full reusability. This vehicle was designed to carry a crew of four, expandable to six, and a return payload of 500 kg. During the spring semester, a two-stage "flattened" Apollo-type vehicle was developed for comparison. This vehicle was designed with an intended crew of five and, like the bent biconic, a return cargo of 500 kg. This vehicle was designed not only to meet the need for an ascent/descent vehicle, but also to serve as a descent cargo carrier, thus eliminating the need for a separate cargo descent vehicle. In addition, the descent stage serves as the habitat on the Martian surface.

The University of Texas team, in the fall of 1985, designed a Mars surface habitat/laboratory for four persons with an initial 60 days surface stay-time. The two-story habitat has a pre-fabricated lower level which is buried beneath the surface and a geodesic dome upper level which remains above the surface. Analysis concentrated on mass and volume sizing of the habitat and on-site construction requirements and advantages. Utilization of this design for permanent facilities has been suggested.

The University of Texas design team in the spring of 1986 devised a scheme for reconnaissance of the Martian moons. An initial manned exploration of Phobos was outlined, including a list of possible landing sites and recommended EVA techniques. A modular moon exploration vehicle was designed which can be utilized as a Mars orbital transfer vehicle and possibly as an asteroid exploration vehicle. Analysis concentrated on trajectory optimization, moon science, scenario development, and vehicle configuration design.

LUNAR LAUNCH AND LANDING FACILITIES

Tuskegee University

Tuskegee University participated in a USRA sponsored program with the NASA Kennedy Center, Florida, to design a Lunar Launch and Landing Facility to support the operations of a lunar base and transportation of LUNOX from the lunar surface to low lunar orbit.

It was assumed that the primary goal of the lunar base was to transport the lunar oxygen to low earth orbit after transporting it to low lunar orbit. It was therefore realized that saving of weight of the Cargo Transport Vehicle (CTV) for lunar oxygen was very important. Each pound of the weight saving of hardware directly transformed into net gain in the payload capacity. Therefore the design of launch and landing facility incorporated a hybrid design which allowed the CTV to land and takeoff in a dual mode. Launch mode consists of an electgromagnetic assistance to achieve at least half of the escape velocity needed to transfer LUNOX to LLO. After achieving this velocity, the main engines are fired to accelerate the CTV to the final velocity. Landing of CTV is achieved using a chemical propulsion system. Considerable weight savings in the form of less propellant requirements for takeoff are envisioned.

Preliminary launch and landing facilities site selection, crew requirements, control tower, landing pads location and the subsystems configurations were studied, and a layout is presented.

Power requirements for the crew and operation of the facility, hybrid launch systems, navigation/communication, and lunar surface transporters were calculated and recommendations are made for a combination of nuclear, solar and fuel cells to provide the power needed.

ADVANCED LUNAR SURVEY SYSTEM

Virginia Polytechnic Institute and State University

The purpose of this project is to design an Advanced Lunar Survey System to determine the feasibility of a permanent manned lunar base and to provide groundwork for future lunar activities. To accomplish this, a manned base camp will be established on the moon in 2005. This camp will perform experiments to examine the lunar environment in greater detail.

The development of the Advanced Lunar Survey System was broken into three components: transportation, lunar habitat, and lunar mobility. The transportation system carries the lunar habitation and lunar mobility system from Low Earth Orbit to the lunar surface. The lunar habitation system provides living quarters and laboratory facilities for the base crew. The lunar mobility system provides a pressurized roving vehicle for extended exploration and experimentation in the lunar environment.

Four vehicles make up the transportation system. First, the Lunar Transportation Vehicle (LTV) carries components of the other systems to lunar orbit. The LTV employs a liquid hydrogen-liquid oxygen engine for primary propulsion. On return to Low Earth Orbit the LTV uses a three pass aerobraking maneuver to circularize its orbit.

The function of the remaining three vehicles is to lower payloads from lunar orbit to the lunar surface. The Expendable Payload Lander (EPL) carries large structures such as the habitation unit one way to the lunar surface. The Manned Descent/Ascent Lander (MDA) transfers the crew and small payloads to and from the surface. Finally, a Special Payload Lander (SPL) is used to transport intermediate weight payloads one way to the lunar surface.

The lunar habitation system provides a habitat and a laboratory for the crew. The system consists of three separate structures: the Habitation Module (HAB), the Laboratory Module (LAB), and the Interconnecting Unit (ICU).

The HAB and LAB modules will provide a suitable living environment, sufficient life support capability, and the facilities for scientific experimentation during a 120 day mission on the moon. Studies of lunar geology, lunar radiation, biological and physical adaptation to 1/6-g. Structural, physical and thermal properties of lunar materials, and plant growth will be done.

The ICU provides the primary exit and a passageway between the HAB and the LAB modules and the primary egress from the base. The ICU also provides the interface between the lunar base and the Pressurized Lunar Exploration Vehicle.

MULTI-MEGAWATT NUCLEAR POWER SYSTEM FOR LUNAR BASE APPLICATION

University of Washington

The conerstone of any successful lunar base is the avilability of large amounts of power: power to conduct scientific experiments, power to process industrial materials, power to expand the base using lunar resources. In addition to a large output, a lunar power generating system must possess a high degree of reliability to permit continuous operation for long periods of time with minimum maintenance, and as small a mass as possible to minimize the cost of transporting the system from Earth. Currently, nuclear power offers the most reasonable approach to power needs exceeding the megawatt level. Accordingly, a 3 MWe power system having an operating life of ten years was elected as the design study goal. A particular aspect of the design presented here is the assumption that the system must inevitably start from space-based power units adapted for surface conditions. The nuclear power system was therefore chosen to consist of elements which could, for example, provide power for a space-based electric propusion system and be disassembled in orbit for reassembly on the lunar surface.

The nuclear reactor supplies thermal energy to the dynamic converter which generates electricity for the lunar base utilities and also produces waste heat which must be radiated to space by a suitable lightweight radiator. Both liquid-metal and gas-cooled nuclear reactors were considered and it was found that the gas-cooled type best met the design requirements. Both particle bed and fuel pin reactors were investigated.

Due to the intense radioactivity associated with a nuclear reactor, it is necessary to provide some form of shielding to protect personnel and equipment in the vicinity of the reactor. Current shielding concepts by industry include burying the reactor in the lunar regolith. Closer examination, however, reveals that the high atomic weight elements in the lunar soil will backscatter neutrons, creating a detrimental impact on criticality levels in the reactor. Radiation shielding is therefore important, and since shield mass is roughly 20% of the entire system mass, a careful optimization of radiation attenuation versus shield mass has been carried out.

The power converter is a high efficiency (33.6%) regenerative Brayton cycle wich uses advanced, lighweight direct-contact heat exchangers of the liquid droplet type to transfer waste heat to the radiator system. Heat rejection to space is effected by a liquid droplet radiator (LDR) which uses the high surface-to-volume ratio of small spherical droplets of a low vapor pressure liquid for efficient radiation of waste thermal energy. The LDRF design presented here offers adaptability to changing environmental conditions and power system requirements, and represents a significant advance in the ciritical area of thermal management in airless planetary environments.

Both the reactor and LDR require structures to support them above the lunar surface. These structures were designed to be erected with minimal construction effort and equipment and to permit straightforward maintenance. Furthermore, the structures and other components were designed to be compatible with launching to LEO in Shuttle cargo bay. It was assumed that transfer from LEO to the lunar surface would be accomplished with OTV's capable of handling Shuttle-sized payloads. Although the fully deployed structures turned out to be large, they were found to have a relatively small total mass.

One of the important findings of this design project is that space-based nuclear power systems readily adapt themselves to a surface environment without significant mass penalties. The specific power of the system presented here is 66 W/kg, which compares favorably with advanced space-based nuclear power system being considered by NASA and DOD.

MARS HABITAT AND RELATED SUPPORT

University of Wisconsin-Madison

The following four major topics were investigated: 1) Habitat structure, 2) Mars rover, 3) Oxygen production, 4) Greenhouse lighting.

1) HABITAT STRUCTURE

In the coming decades, one of NASA's major projects will be a permanent base on Mars where a crew of 11-15 astronauts could live and work for two years shifts. Last year, the Engineering Mechanics Design class proposed a feasible scenario using the Martian aerocapture shells for the exterior structure of the habitat. Our goal this year was to further develop and take a closer look at last year's proposal and decide if their work represented the best possible configuration.

Other design configurations along with last year's configuration were evaluated against well defined analysis criteria to determine the optimal design. A detailed development of our final choice was also done. Consideration is given to establishing an initial Mars base. Tipping and transporting the aerocapture shell is addressed. Properties of Martian regolith are tabulated and examined for use as a radiation shield and for design of regolith moving equipment. Improvements on the current Martian Habitat design were requested. A Needs Analysis, Problem Statement, and Design Criteria were developed. Preliminary designs were proposed based on these parameters and the four best were chosen for futher analysis. Design criteria were weighted according to mission importance. The designs were evaluated with the weighted criteria in a Comparison Analysis. Recommendations to improve the Martian Habitat design included a modular exterior construction, a centrally located inflatable green house, and a pressurized work area.

General design procedures were performed on the above subtopics including stress analysis and material selection for the inflatable and modular structure, and methods for connecting the modules.

2) MARS ROVER

When the first humans land on Mars to start a permanent base, they will need some sort of vehicle to help build that base. This vehicle is being designed to produce a large power output, and therefore, the power supply must run on an easily accessible fuel or energy source. The locomotive structure is designed in order to provide maximum traction, and is of an articulated design. A stabilizing platform is used to minimize pitch, roll, and yaw movement of the vehicle equipment and operators. A corresponding structure design will be needed to actuate the vehicle components. Weight and size are optimized with a power train system utilizing hydraulic drive. Power from this system will be transmitted to specially designed wheels for the Martian terrain.

3) OXYGEN PRODUCTION

The portable Self-Contained Oxygen Production Unit described in this report brings together current technologies for the support of manned missions to Mars at a future date. The device is designed to provide a breathable air supply for direct interaction with the Mars atmosphere using current space suit design criteria (i.e., 8 psi internal suit pressure and a 60%-Oxygen/40%-Buffer Gas mixture) and to contain this life support apparatus within a back-pack unit. An adsorption pump raises the average ambient atmospheric pressure from 0.1 psia (7 mb) to an acceptable pressure for passage into the Sabtier reactor which converts CO_2 to H_2O. Final conversion of the CO_2 dominant atmosphere to O_2 acceptable for breathing is through the electrolysis process. This converts water that enters the electrolysis chamber into liberated O_2 and hydrogen (which is recycled in the system) through the use of an electrical potential. Buffer gas supply is considered through initial system charging and recycling using molecular sieves. Exhaled CO_2 offers reusability at a higher efficiency than extraction from the atmosphere. Criteria for effective design of this device are based on the current 1986 level of knowledge of the Mars atmosphere and surface conditions. Along with identifying the feasibility of this device for future work in the life support area, notice is made of current areas of technology which fall short of the requirements for this or similar projects.

4) GREENHOUSE LIGHTING

The paper is a design for an artificial lighting system for a Mars based growth chamber. High pressure sodium lamps are used as the lighting sources. An air cooled, vertical adjustment, direct lighting fixture system was found to be the most functional with minimum weight and maintenance.

LUNAR ECOSYSTEM AND ARCHITECTURAL PROTOTYPE

*University of Houston **
Presented by: Sam Ximenes, Francis Winisdoerffer, Jeffery Brown

Presented are concepts for an initial lunar base, which can serve as the core facility for larger lunar settlements as needs and activities evolve. These concepts expand previous research and design work undertaken at the University of Houston's Center for Experimental Architecture and other organizations. The study emphasis is upon requirements and opportunities associated with early stages of habitat construction applying a modular systems approach.

A reference lunar base design with a growth configuration scenario is illustrated using computer generated three-dimensional models to demonstrate means of achieving large volumes of habitable space. The base is designed as a lumar ecosystem and architectural prototype capable of evolutionary growth toward self-sufficiency. Use of indigenous lunar materials for construction is recognized and design studies of alternative architectural/material concepts are applied.

**The University of Houston was not a member of the Advanced Space Design Program; however, a relevant study was underway under the Department of Architecture and they were invited to report on it at the conference.*

Workshop Summaries

SPACE AND REENTRY ENVIRONMENTS WORKSHOP

R. C. Kennedy, Johnson Space Center

To bound the discussion, the environments were defined as follows:

Natural	Induced
Vacuum	Reentry Thermal
Solar Thermal	Debris (Man-Made)
Particle	
Radiation	
Planetary Atmospheres	
Gravity	

The discussion was also constrained to the Sun-Earth-Moon-Mars system.

For the above environments the questions before the panel were: (1) Is the state of our knowlege sufficient and if not (2) will further research reduce the uncertainty to significantly relieve or reduce design constraints. That is, what areas could most profit from sponsored research?

Consensus statements are as follows:

Vacuum, Solar Thermal, Particle

Models are adequate for spacecraft/mission design

Radiation

Mean models are adequate for preliminary design. There may be variances in detail when applied to a specific problem.

Perturbations from solar events cause the biggest problems. Research is needed to establish better prediction techniques.

Planetary Atmospheres

Earth models are generally adequate but further research is required to reduce the uncertainty of localized high altitude variations.

Mars model is adequate for design. Research to correlate large disturbances (i.e., dust storms) with Martian seasons or other parameters would be useful.

Gravity

Models of Earth and Moon are adequate. The Martian model needs more definition. It would be useful for a future unmanned orbiter to map the field.

Reentry Thermal

Research is needed to better model the chemistry and flow field thermal parameters of non-equilibrium radiative heating.

Debris

Statistical models of man-made debris (from break-up of spacecraft and dead spacecraft) should be developed and published.

GEO clutter will become more and more of a problem unless remedial action is taken. Probably requires international agreements and control.

Work-arounds could include clustering of a large number of transporters on a single spacecraft to reduce the number of spacecraft required. Alternate orbits, such as halo orbits, may have a potential for creating more useable space.

Post-briefing comments

A low-density "haze" layer exists at the lunar surface which may impact scientific (surfaced-based) instruments such as telescopes. This "atmosphere" should not affect spacecraft/mission design.

There may be a large number of potential conflicts between lunar surface based science and the system needed for future lunar exploration and exploitation. For example, drilling and mining may interfere with seismology instruments and research.

AUTOMATION & ROBOTICS WORKSHOP

J. D. Burke, Jet Propulsion Laboratory

I. INTRODUCTION

The group considered automation and robotics technology needs for the missions considered at this conference. In what follows, we describe (1) technology needs for advanced lunar and martian missions, (2) key technology tasks in the field of automation and robotics, and (3) research areas in this field that appear to offer high payoff for these missions.

II. MISSION TECHNOLOGY NEEDS

A. *Lunar missions*

Lunar automation and robotics will support (a) transport to and from the Moon, (b) human residence there, (c) scientific activities on and from the Moon, and (d) exploitation of lunar resources. Priority technology tasks are as follows:

1. Improvement of automated rendezvous, docking, and materials, fluids, and personnel transfer. This is closely allied to guidance, control, and manipulation research but

it is applied to entire space vehicles in proximity and in contact.

2. Improvement of automated and robotic living-systems control under lunar conditions. In the long run this development could lead to automated lunar farming.

3. Development of multipurpose, mobile robots for use in and around lunar bases. This task can include many subtasks in the realm of sensing, deciding, and acting as shown under "vehicle autonomy" on Figure 2. However, the emphasis in these subtasks for *lunar* rovers will be more toward teleoperation, while for *martian* rovers (see Section B, below) it will be more toward autonomy.

4. Improvement of a variety of sensors, including scientific instruments, for operation under lunar conditions. Technology tasks here could include adaptation of advanced Earth-based techniques toward high autonomy and longer untended operation; e.g., of cryogenic focal-plane assemblies for infrared telescopes.

5. Development of high-power (megawatts and above), long-lived energy control systems and maintenance (and possibly repair) robotics systems for use with lunar nuclear powerplants, lunar solar furnaces, and lunar heat-rejection subsystems.

6. Robotics and automation for lunar mining, processing, transport and manufacturing using lunar products, with lowering final product cost (e.g., lunox to LEO) as a dominant criterion.

B. Martian missions

Martian automation and robotics will also support transpower, residence, science, and resource utilization but the nature and relative priority of technology tasks will differ. Priority tasks related to manned Mars missions are:

1. Manipulation of very large objects, in inherently non-rigid combinations, as will occur during on-orbit assembly of trans-Mars injection vehicles.

2. Robotic support of crews during transit to and from Mars, including automated maintenance of habitat conditions, with anticipatory sensing to extent feasible.

3. Adaptive aerobraking control.

4. Sensing, control, and display technology for descent and landing on Mars, with research, simulation, and demonstrations to optimize human-machine interactions during this critical mission phase.

5. Automation and robotics support of human surface activities on Mars, with same general elements as on Moon but with different emphasis at least in early stages; for example, no applied agriculture but some plant-growth experiments. Rovers with higher autonomy.

6. Automated in-situ chemical processing such as CO and oxygen recovery from the martian atmosphere.

C. Technology tasks applicable to both lunar and martian missions and/or relating to precursor missions and adjunct or support functions.

1. Manipulators with light weight (e.g., by using inflatable elements) and with anticipatory sensing at the point of grasping and manipulation.

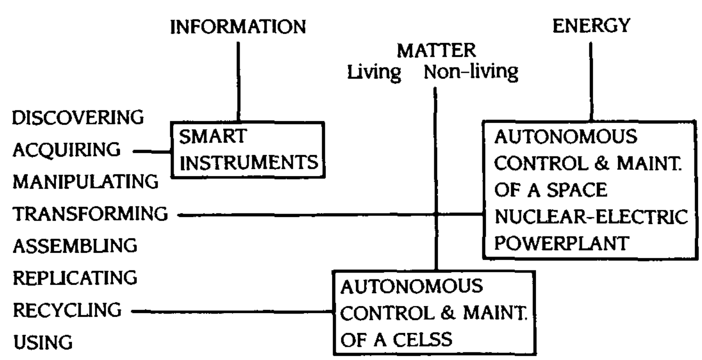
2. General-purpose tool kits adapted to manipulator end effectors.

3. Improved world modeling in memory of mobile robots; improved decision algorithms.

III. HIGH PAYOFF RESEARCH FIELDS

A. New computer architectures for fast parallel and multi-level processing, as needed in hierarchical control systems.
B. Miniaturization of all kinds, permitting, for example, such sensors as microscopic eyes in the ends of fingers.
C. New, highly-automated propulsion techniques such as laser-driven fusion with magnetohydrodynamic thrusters using superconducting coils. In principle, such techniques could drastically reduce Earth-Mars-Earth transit times and thereby exert strong leverage on other needs such as long-term crew health maintenance.
D. Automation and robotics of space nuclear powerplants, including repair potential.

EXAMPLES OF APPLIED ROBOTICS & AUTOMATION



INFORMATION ROBOTICS R&D

- ADAPTIVE INSTRUMENT PRINCIPLES: HOLOGRAPHY, SPECTROMETRY, TOMOGRAPHY
- AUTONOMOUS REASONING
- MACHINE → HUMAN → MACHINE COMMUNICATIONS
- VEHICLE AUTONOMY:

SENSE, COMPREHEND, EVALUATE, DECIDE, ACT

(WORLD MODEL)

UPDATES

NEEDS:
- BETTER WAYS TO ENCODE WORLD MODELS IN MEMORY
- BETTER COMP/EVAL/DECISION ALGORITHMS
- SMART SENSORS AND EFFECTORS

MATTER ROBOTICS/AUTOMATION R&D

- ADAPTIVE EFFECTOR PRINCIPLES

REALTIME LOCAL CONTROL VIA, E.G.:
- FORCE
- DISTANCE
- TEMPERATURE
- REFLECTIVITY
- SHAPE
- CHEMISTRY

SENSING → ACTION

APPLICATIONS:
IN-SPACE ASSEMBLY
AUTO. RENDEZVOUS/DOCK
MINING/TRANSPORT
LIFE SUPPORT
AGRICULTURE

- VEHICLE-TO-VEHICLE COÖRD; E.G., COMPUTER IN ONE DRIVES EFFECTORS IN OTHER

EXAMPLE: MARS SURFACE RENDEZVOUS
- ACTIVE MULTI-ELEMENT DAMPING OF LARGE STRUCTURES
- ADAPTIVE TRAJECTORY CONTROL (E.G., IN AEROBRAKING.)
- EFFECTORS & TOOLS WITH FORESIGHT - INFLATABLE GRASP

ENERGY ROBOTICS/AUTOMATION R&D

- EFFICIENT CONVERSION VIA AUTONOMOUS SYSTEMS
  - NUCLEAR HEAT EXTRACTION, USE AND REJECTION
    - LUNAR BASE
    - MARS CAMP
    - VEHICLES
      - SURFACE
      - ORBITAL
  - NUCLEAR → ELECTRIC CONVERSION
  - SOLAR HEAT → ELECTRIC CONVERSION
  - SOLAR → ELECTRIC
  - MECHANICAL (E.G. WEIGHT LIFTING)
- ENERGY TRANSMISSION, DISTRIBUTION
  - LASER BEAMS
  - RF
  - FIBERS, PIPES, WIRES (LOCAL MATERIALS)

SPACE MANUFACTURING WORKSHOP

W. Mendell, Johnson Space Center
J. Nichols, Auburn

We began our group meeting by reviewing the study projects of the participants and then discussing what elements related to space manufacturing. We identified products and processes and asked in each case why the particular manufacturing activity was chosen as a subject for study. We wanted to address the broader question of rationale for moving manufacturing to the space environment as well as defining specific research issues arising from the studies.

Our first observation was that the term "space manufacturing" applied to production on the surfaces of the Moon and Mars and was not limited to work on the Space Station. Although the observation seems trivial in the present conference, it is important to realize that research in planetary engineering is sparsely represented in current NASA programs. Therefore, recommendations arising from student studies can have a high leverage in shaping future research initiatives in NASA.

In choosing a research project, some groups tried to find a process which takes advantage of the space environment to produce something better than terrestrial equivalents or to produce something unique. This rationale is applicable to any extraterrestrial setting but seems particularly well suited to the free fall environment of a space station.

On the other hand, most projects applied familiar terrestrial engineering experience to the extraterrestrial context. Those studies concentrated elements of supporting space infrastructure and tended to be set on a planetary surface. As we move to planetary bases, our vast storehouse of engineering expertise in the economy as a whole will begin to find application to space development in familiar ways.

Most of the reasons for manufacturing products in space stemmed from the high cost of Earth-to-orbit transportation. For example, the initial cost of shipping to the lunar surface will be something like $700 per ounce, approximately twice the price of gold. In such a situation, lunar products produced locally can have a competitive edge, even after cost of capitalization for production is taken into account. As large structures are built in space or as the intensity of activity grows, lunar materials may be economical to ship to Earth orbit. Structural materials may be shipped in unprocessed form due to the difficulty handling beams and structures during aerobraking into Earth orbit.

Another reason for producing commonly used products such as liquid oxygen on the Moon might come from limited launch capacity to low Earth orbit. High value goods that can only be produced on Earth may be given priority for limited cargo volume.

In the future, planetary or asteroidal resources may become valuable if strategic elements on Earth become depleted or unobtainable. Finally, there is the nagging question whether any element available on the Moon is valuable enough today to ship to Earth. In general, the answer has been in the negative; but recent work at the University of Wisconsin suggests that the rare isotope ^3He may be mined on the Moon to support a terrestrial fusion power industry.

It was pointed out by the group leader that work in exploitation of space resources may be useless unless legal questions regarding using the Moon are resolved. Currently, these activities appear to be restricted by treaties in effect and others proposed. NASA must investigate these legal issues as well as technical ones.

To carry out manufacturing in space we must identify exploitable resources, develop the technology to access them, find the markets for the products, and invest the capital to establish production. The question of technology development is the one relevant to this group. However, the participants emphasized that the first step, identification of resources, is overdue. Unmanned precursor missions to the Moon, Mars, and the asteroids are needed. Near-Earth resources is a new theme emerging in NASA's planetary exploration program, but the requisite missions are still in the future. Meanwhile, lack of knowledge about the nature of the ore bodies adds uncertainties to the design of any manufacturing process.

Specific shortfalls in the technology information base were noted:

(a) A handbook for design in space needs to be made widely available. What kinds of lubricants and bearings are appropriate? What materials give problems in vacuum (e.g., low vapor pressure of cadmium)? What motor designs are suitable? How well does machinery operate in space?

(b) Many engineering handbooks are full of empirical data. How does that information translate to lunar gravity or microgravity? For example, what are appropriate design parameters for a distillation column on the Moon? How amenable to theoretical analysis is the design of heavy machinery such as earth movers or large lathes?

(c) How efficient are humans as workers in reduced gravity? What supplies are needed to support a worker in the space environment? These questions must be addressed before a designer can make decisions about the proper mix between man and machine and on the degree of automation.

(d) What solar energy designs are appropriate to use on the Moon? In particular, what characteristics can be assumed for solar energy concentrators (e.g. temperature, energy throughput, heated volume)?

(e) What is the pressure in a "pressurized" lunar habitat? And what is the atmospheric composition?

(f) Information must be made readily available on the lunar and martian environment.

(g) The capacity of various elements of the space transportation system must be made known to designers so they can decide whether machinery can be shipped as a unit or must be assembled at the destination.

(h) Information is unavailable on whether designs of machines will work when operating on the Moon and in space. Right now, designers only understand the static case. On the Moon, the only data for operating machinery comes from the Lunar Rover, which was designed for a short lifetime.

STRUCTURES AND MATERIALS WORKSHOP

J. Youngblood, Langley Research Center
H. Buning, U. of Michigan

Many common mission elements; differences arise via relative mission durations (longer to Mars), relative solar distances, and from environmental differences between Mars and Moon. Man's presence assumed in all cases.

TECHNOLOGY NEEDS

STRUCTURES

- Control of large, flexible space structures
- Inventory of generic components for space construction—
  Bricks, Panels, Beams, Wire/cable (guys, rigging, tethers)

MATERIALS

- Films
  - Shielding—Thermal, radiation, conductive, adhesive, lubricating
  - Pressure proof (Habitat, Fluid storage)
- Foams
  - Void Fillers (Mortar)
  - Rigidizing
- Extrudable/Pultrudable Compounds
  - Epoxies
  - Fiberglass
  - Ferromagnetic (or equiv.) materials (for electric motors and other devices. These represent significant mass fractions in power systems. Can they be manufactured in space??)
- Heat Shield Materials (Direct entry, multipass aerobraking)

TECHNOLOGY TASKS: ANALYSIS, R&D

STRUCTURES

- Develop control techniques, including piezoelectric & thermoelectric control elements.
- Perform hardware design & test
- Evaluate concepts on space station

MATERIALS

- Evaluate behavior of materials in close static & dynamic contact. Assess cold welding tendencies & friction characteristics. Ground & on-orbit tests
- Develop lighter-weight aero heat shield materials. Consider trades among material properties (heat capacity, max. heat rate tolerance, ablation/erosion characteristics, et. al.) and trajectory design. E.g., it may be appropriate to minimize number of atmosphere passes in an aerobraking emergency.
- Evaluate secondary radiation characteristics of selected materials. Trade degree of radiation risk against cost, size, mass, complexity, or reliability of protective system. (Treat man as a material/system in this context.)
- Develop methods for tailoring materials to meet specified needs. This is a catch-all, but nonetheless important.
- Assess requirements for foam, fillers, and films.
  - Space super glue?
  - Void filler (mortar)
  - Foams (controlled expansion)
  - Thermal control & radiation-resistant coatings
  - Lubricants

Develop & test under simulated conditions

Test on space station

- Evaluate materials used in habitat construction
  - Non-noxious
  - Vibration & Acoustic damping
  - Color, Texture effects on inhabitants

Ground & space testing required.

- Evaluate hardware AFTER long-term space exposure
  - Accelerate/resume analysis of retrieved hardware on hand
  - Retrieve LDEF and/or launch second LDEF
- Retrieve other orbiting or landed spacecraft or identifiable debris.

SPACE POWER WORKSHOP

L. Kohout, Lewis Research Center
A. Bruckner, U. of Washington

The consensus of the group is that the general trend for future space power systems is toward higher power levels, longer life (10+ years), and increased reliability. Systems capable of supplying megawatts of power will be required to support such missions as lunar and Mars bases. Missions requiring lower power levels, on the order of tens or hundreds of kilowatts, will also be prevalent. The group agreed that photovoltaic systems are viable for missions requiring less than 100 kw while solar dynamic systems are applicable in the range of 100-300 kw. To achieve higher power levels, nuclear systems appear to be the most practical for most applications, since they are lighter and more compact than solar-based systems. Of course, the best power system technology for a given mission can be chosen only after a detailed mission analysis is performed.

The students who participated in the group dealt mainly with nuclear power systems in their projects; therefore, most of the discussion focused on nuclear technology. A major obstacle encountered by the students was the lack of adequate data bases for optimum siting of a reactor, gamma shield modeling and materials, and standards for human tolerance of radiation.

In the area of shield modeling, a simple conputer code would be helpful. Codes such as CADRE exist but the data base is limited as well as widely scattered.

Information on the use of lightweight shielding materials such as $ZrH(B_4C)$ (borated zirconiumhydride) is sketchy. Most of the published information deals with tungsten shielding which is too heavy to be practical for an advanced mission.

There have also been some discrepancies in the reported dosage of radiation that can be tolerated by humans. Values range from 35 REM/90 days for NASA to 80 REM/90 days for the Soviet Union. Since nuclear safety is such a critical item for the manned missions, the lack of adequate data bases was a hindrance to the proper design of the power system. A member of the working group suggested contacting the New England Research Applications Center to obtain any available references from work done on nuclear power in the 1950s and 1960s.

Another interesting question that arose during the discussion was the decommissioning of planet-based nuclear reactors. This was not addressed in the project designs due to a lack of information. However, it should be considered, especially when looking at lunar or Mars colonization missions.

Some areas for technology development were identified during the course of the workshop session. As the power levels increase, the heat rejection requirements also increase, placing more demand on the radiators. Present day radiators, incorporating fin-tub, or even heat pipe technology, tend to be a mass driver for the overall system. Clearly, lightweight radiators will be a necessity for the high power spacecraft of the future. These include liquid droplet, liquid belt, and bubble membrane radiators. New, lightweight materials should be investigated for use in the construction of shields, which also tend to be mass drivers for nuclear systems. Advanced energy conversion cycles having higher efficiencies than present state-of-the-art conversion cycles also represent an area for technology development.

Alternatives to nuclear power should not be overlooked as new technology development areas. Development of advanced heat receivers for solar dynamic systems will result in more efficient systems and heretofore higher specific powers. These advanced concepts include flowing gas and LIF particle receivers. Power generation via the use of fusion reactions, specifically utilizing D^3He, may be possible and should be investigated. This concept is, of course, a longrange option.

As research opportunities for the universities, many of the studies concerning nuclear power are impractical from a safety standpoint. Most facilities are not adequately shielded and protection is needed against possible radiation contamination. However, the development of computer codes for shield modeling or the investigation of new radiator or receiver concepts is highly adaptable to the university environment.

INFORMATION SYSTEMS/COMMUNICATIONS/ DATA REQUIREMENTS WORKSHOP

S. Paddack, NASA Goddard
W. L. McCracken, U.S. Naval Academy

The group first addressed the problems faced by each in their own group and expanded that to problems currently faced in this area by all space vehicles.

INFORMATION PROBLEMS

- OUTDATED SYSTEMS
- MODULARITY
- COMMONALITY
- STANDARDIZATION: FORMAT
  - DATA BUS
  - INTERFACES
  - LANGUAGE
  - DOCUMENTATION
- AMOUNT AND QUALITY
- NEED SELF-HEALING DISTRIBUTED SYSTEM
- AUTONOMY

To solve the listed problems, basic technologies need to be pursued.

AREAS NEEDING ADVANCES IN TECHOLOGY OR NEW AREAS OF TECHNOLOGY

- VHSIC: VERY HIGH SPEED INTEGRATED CIRCUITS
- PROTECTION OF SPACE ENVIRONMENT EFFECTS:
  - Cosmic Ray Damage
  - Gamma Ray Damage
- FAULT TOLERANT SYSTEMS
  - Diagnosis
  - Self Healing
- AUTONOMOUS SYSTEMS
  - Expert Systems
  - Artificial Intelligence
- OVERCOME SPEED OF LIGHT LIMITATIONS

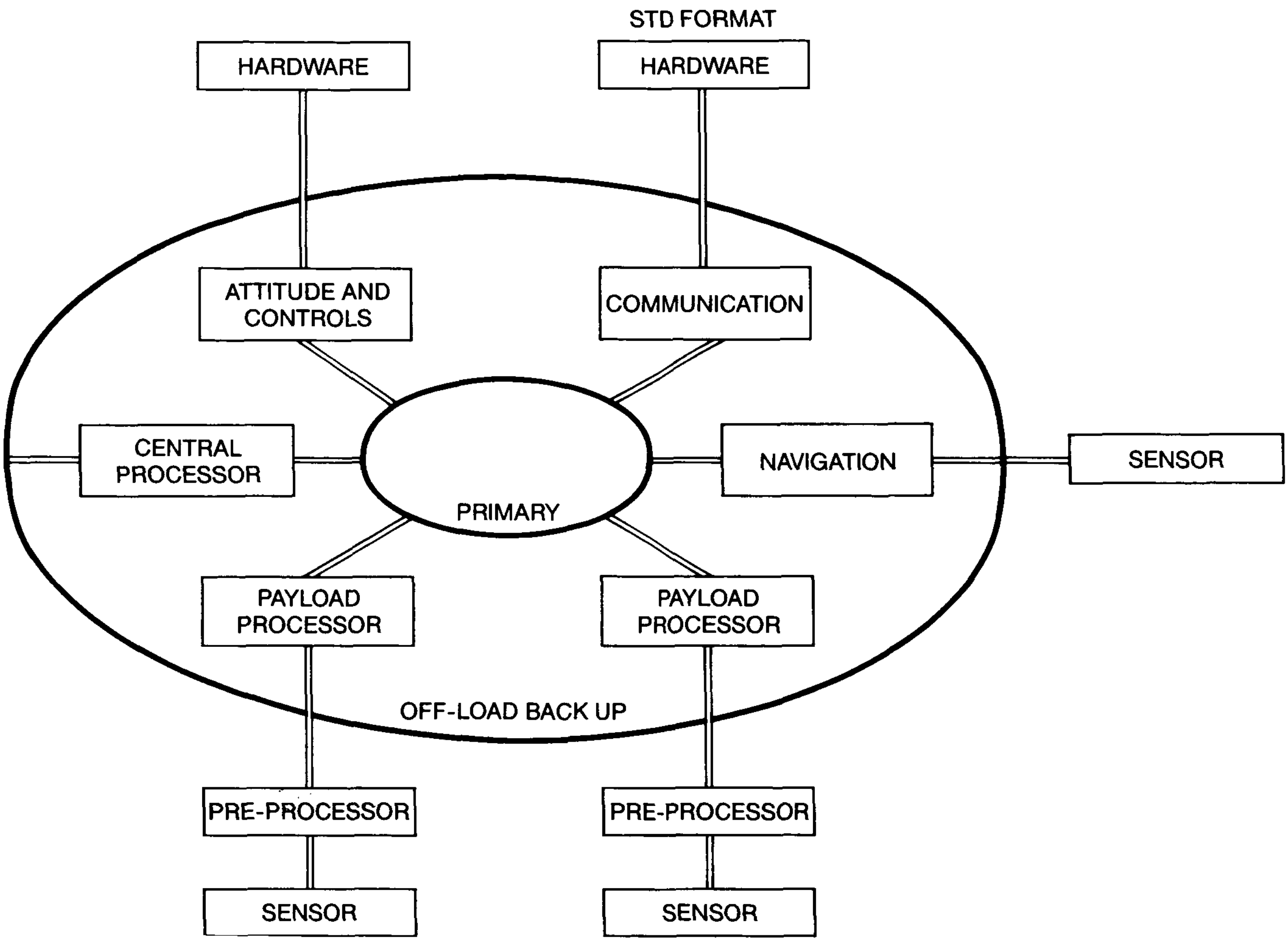
The first area addressed in detail was the need for data processing needed by the space vehicle for it to achieve autonomy. As space vehicles leave the Earth-Moon system for tasks such as deep space exploration, solar system exploration, planetary exploration, and planetary construction, the space vehicle must independently solve problems and perform tasks with less dependence on communication with the Earth. This area of artificial intelligence and expert systems must be evolved with each new capability building on the previous. This evolution begins with intelligent monitoring and diagnosis and builds to the vehicle capable of learning from its own experiences.

EXPERT SYSTEMS

- INTELLIGENT MONITORING/DIAGNOSIS
- SPACECRAFT CONTROL HEALTH/WELFARE
- AUTONOMOUS PLANNING
- INTELLIGENT CONTROL
- LEARNING

The last area addressed is the need for standardization. The current uniqueness of the information systems onboard space vehicles has led to numerous problems. Information developed on one program does not easily transfer to the next, leading to more unique designs, group stations, and communication uses. When a problem occurs on a vehicle, only the individual design team personnel can understand it. Without standardization, when a key engineer leaves a team, he takes with him the knowledge of the area he uniquely designed.

To overcome, this problem, the team looked at possible areas of standardization. All space vehicles have certain areas in common. These are Communication, Navigation,



TWO STANDARD BUSSES
STANDARD INTERFACES } SIZE, RATE, LANGUAGE

ALL PROCESSORS ABLE TO HANDLE TWO FUNCTIONS (PRE-PROGRAMMED)

Attitude Control, Data Storage, Data Processing and unique processing of Payload/Sensor information.

The group recommends that a standard core system be developed that would be utilized in all space vehicles. This core system would provide data processing for all the common needs of each vehicle. The key boundaries would be multibus access to all processors and peripherals. This allows for development of a self-healing, distributed system. In the case of any processor failure, another processor would pick up the load. Standardization is achieved by having a standard bus structure, standard data structure, and standard interfaces to the bus. A preprocessor would be required to ensure that each peripheral interfaces with the bus as required. With this standard capability available in each vehicle, time and energy can be better utilized developing the unique sensors and capabilities required by the vehicle's specific mission (Diagram next page).

TWO STANDARD BUSSES
STANDARD BUS INTERFACE UNIT (BIU)
SS BIU CONTAINS PROCESSOR,
This bus (below) does not require a separate processor.

PARALLEL BUS:

Data	Org.	Dest.		
128	10	10	In Use (1)	Req. (1)

Priorities implemented by preemption on multibit priority in Req. field.
PRE PROGRAMMED
DUAL FUNCTIONS IN EACH PROCESSING UNIT.
DUAL BUS:

- TWICE THE BANDWIDTH W/BOTH BUSSES UP.
- REDUNDANCY WHEN (IF:) FAILURE.
- EACH BUS TAKES DIFFERNT PHYSICAL PATH.
- BUS CAN BE COMPOSED OF DIFFERENT MATERIALS (?)— Possibly one bus a serial version of the other parallel bus.

PROBLEMS: (Must be more!)

- When in dual function mode, how is interface to node-specific instruments handled? i.e., how does payload controller talk to antennae in case of communication failure?
- TIMECLOCK/TIMESTAMP GENERATOR
- COMM PACKET ORG. ON DOWN LINK— WHERE IS STANDARDIZATION?

MISSION PLANNING WORKSHOP

B. Roberts, Johnson Space Center
W. T. Fowler, U. of Texas
S. P. Nichols, U. of Texas

Definition

The objective of mission planning is to develop, describe, analyze, critique, and improve the elements of program activities leading to the realization of the established space agency goals and objectves.

The process of mission planning is initiated as the result of having a mission goal defined and having top level mission objectives developed. A mission plan is developed as the top level mission objectives are assembled into alternative mission scenarios. The scenarios are compared using engineering trade studies, cost-benefit analyses, critical technology assessments, and risk analyses. The final choice of a mission scenario and plan may be made on the basis of cost, risk, engineering trades, political factors, etc. Any mission plan has long range implications in terms of agency policies, long range goals, resource allocations, future research thrusts, and tomorrow's technology inheritance. Additionally, future mission plans are subjected to outside review for the purpose of advocacy searching and reality testing.

MISSION PLANNING

The Process

In mission planning, the top level objectives evolve into candidate mission scenarios in an iterative process which involves definition of detailed requirements and consideration of constraining factors. Further studies of viable candidate scenarios include definition of mission elements, infrastructure requirements, and critical technologies. Next, discriminants are developed to facilitate the choice between candidate scenarios (cost-benefit analyses, risk analyses, engineering trades, etc.)

The results of each iteration of the mission planning cycle must be subjected to a thorough "reality test" (feasibility and practicality assessments by qualified and unbiased experts). The planning process should *always* include development of several plans which pass the reality test.

Each step of the mission planning process requires that a large quantity of diverse data be assembled and assessed. The process of assembly and assessment implies the existence of appropriate data collection, assessment, and dissemination tools.

Tools for Mission Planning Analyses

Mission Planning for long term (possibly multi-decade) programs that have varying paths to success requires tools of analysis more sophisticated than traditional PERT/CPM type analyses generally used in planning exercises. The planning tools needed for Advanced Mission Analyses must include the following elements:

1. *Strategic Planning Models.* (Perhaps at this level, the tools most resemble PERT/CPM analyses.) These models should help identify critical technologies which are necessary in one or more than one of the mission objectives.

2. *Technology Forecasting.* Not only must the analysis anticipate development of technology but it must also "force" the assessment of the risks of failure involved in each development. If the technology is critical and has a high degree of doubt as to ultimate chance of success within the required timeline, alternate technologies must be identified and pursued.

3. *Cost Models for Advanced Systems.* The analysis must consider the cost of each element and the cost of supporting alternate approaches for critical technologies (See element 2).

[Authors' Note: The results from the first three elements mentioned yield a trade-off of Time/Risk-of-Failure/Costs which must be carefully analyzed. The analysis techniques should be flexible enough to allow quick response to a broad range of "what if" questions. Examples are (1) What effect would a 50% increase (decrease) in budget this year have on the Cost/Time/Risk associated with the mission? (2) What is the Benefit/Cost of carrying multiple paths to success to meet a particular requirement? (3) If multiple paths to success are pursued, how many and which paths should be funded and at what levels? etc.]

4. *Socioeconomic Forecasting.* The first three elements describe the planning analyses of considerations largely within the control of NASA. In order to optimize the chances for successful completion of program goals, analyses should be made of the reactions of both the public and national policy makers to large unexpected deflections in program success (either program breakthroughs or disasters). NASA needs to examine "Inflection Points" in the events of the program and have a least a broad response thought out before the fact. While such an exercise can be quite time consuming, and certainly cannot consider every contingency, the benefits of having thought through possible responses can be quite profitable. At the least, NASA should define what events or combination of events would (more likely than not) cause an abort of the mission goals.

5. *Risk Assessment.* While this element could have well been included as a sub-function of other elements, its importance dictates separate mention. The risk considerations encompass a broad range of possibilities, including risks of (a) technological failure (as discussed above), (b) sociopolitical change, (c) environmental changes, and others.

6. *System and Element Definitions as a Function of International Cooperation.* The model mentioned in Element 1 should be examined in the light of potential cooperation with other nations. The possible alterations in program plans (if any) must be examined and the effects on Cost/Risk/Time to completion should be taken into account.

In order to develop the Mission Planning Analysis Tools described in this section, it is anticipated that some development must take place beyond management tools currently available. (Advanced planning systems exist, and have been used by programs with somewhat similar structural requirements.)

Problem Areas

The primary technological barriers in mission planning lie in the areas of information availability, access, and processing. The access, processing, and data requirements for effective technology forecasting, strategic planning, cost modeling, and risk assessment are extremely large and complex. Social and geopolitical considerations add increased complexity to the mission planning process.

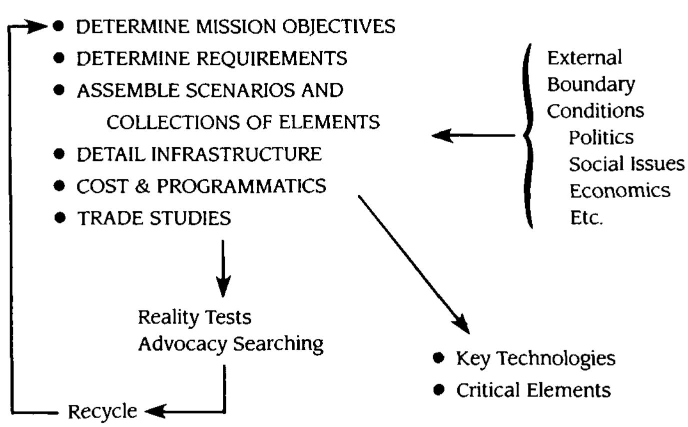
Recommended Actions

It is recommended that NASA explore, prioritize, and proceed with the development of the mission planning analysis tools cited above. The following steps constitute a partial plan toward that goal.

1. Commission an organized and systematic evaluation of the applicability of the broad spectrum of available planning software (commerical, government, academic, etc.) for the task of large scale long range mission planning. The objectives of this evaluation would be (a) to define which tools are applicable to which mission planning tasks; (b) to determine what types of data bases (knowledge bases) and information structures are needed for effective use of these tools; and (c) to determine what tools still need to be developed.

2. Commission a study of information collection and access technologies with the goal of facilitating the access of mission planners to the required large data collection.

THE PROCESS OF MISSION PLANNING IS:



PRODUCTS OF MISSION PLANNING ARE:

- LONGRANGE PROGRAM PLAN
- IDENTIFY COMMON:
  - Elements
  - Systems
  - Subsystems
  - Technologies
- LOWER COSTS/CUT SCHEDULES
  - Synergism
  - Inheritance
- IDENTIFY NEW TECHNOLOGY DEVELOPMENTS
  - Hi-Leverage
  - Enabling
  - Rank-Order/CBA
  - Competitive Technologies
- IDENTIFY IMPACTS TO NEAR TERM DEVELOPMENTS
  - OTO Vehicle Requirements
  - ETO Vehicle Requirements
  - SS Growth Path
  - SS Supported Tech Developments for future missions

REQUIRED TOOLS NEEDING DEVELOPMENT:

- STRATEGIC PLANNING MODEL
- TECHNOLOGY FORECASTING
- COST MODELS FOR ADVANCED SYSTEMS
- SOCIOECONOMIC FORECASTING
- ANALYSIS OF RISK
  Technologies
  Environmental Changes (Goal Deflections)
  Contingency Planning
- IMPACT OF INTERNATIONAL COOPERATION ON SYSTEM AND ELEMENT DESIGNS

PROBLEM AREAS

- INFORMATION AVAILABILITY, ACCESS, AND PROCESSING
  TECHNOLOGY FORECASTING
  LARGE SCALE STRATEGIC PLANNING
  COST MODELS (DATABASE)
- SOCIAL AND GEOPOLITICAL ISSUES ARE
  Significant for > 4 Year Programs
  Complex and difficult to deal with.

SPACE PROPULSION WORKSHOP

K. Sivier, U. of Illinois
F. Swalley, Marshall Spaceflight Center

Propulsion Systems
- Combined cycle engines
- Electric propulsion, e.g., electrostatic, mass driver
  -Nuclear powered
  -Solar powered
- Cleaner "burning" systems to control contamination of orbital assets
- Other fuel possibliities; e.g.,
  -Lunar aluminum-based fuels
  -Methane in the martian system
- Laser heated systems; rocket and airbreathing
- Magnetic plasma dynamics systems
- ^{3}He fusion system
- Anti-matter system
- Solar sailing
- Tethered systems
- Nuclear thermal
- Rail guns

Supporting technology
- Better (lighter) nuclear system shielding; e.g., magnetic shielding
- Liquid air cycle engine
- Improvement in long-term cryogenic storage systems to reduce boil-off performance losses
- Lighter mechanisms to deploy nozzle extensions
- Optimization of low thrust (impulse and continuous) trajectories
- General parametric study of trade-offs between engine efficiency and system performance
- Impact on propulsion system perf. requirements of aerobraking technology.

LIFE SCIENCES/HUMAN FACTORS/ LIFE SUPPORT SYSTEMS WORKSHOP

Y. Clearwater, Ames Research Center
G. Nevill, U. of Florida

1. Primary words to described this conference:
   - Informative
   - Impressive
   - Refreshing
   - Inspiring
   - Frustrating (That there is so very much we have to teach and share with each other and yet time, travel budgets, etc. are such limits.)

2. Frequently had to remind myself that these are undergraduate students. Very good teamwork, high levels of sophistication in many technical areas, enthusiasm, energy—spirit!

3. I think that this kind of "ideation" and encouragement of free thinking is an extremely useful/valuable process, both for the universities and for NASA.

4. Major area needing "improvement:" Better information and support from NASA and industry on life sciences/ human factors issues, current efforts, future problems, etc., re advanced missions.

5. Other suggestions:

A. I would like to see not only good, solid information dissemination from NASA and industry to the schools, but also technical critiques (perhaps at the midterm point in their projects); real "roll up our sleeves and hash out information and issues" collaborative reviews. The students are trying so hard to make their final presentations as professional and first-rate as possible—it's a shame to dampen their spirits by pointing out obvious technical flaws at the final stage. Of course some of that (pot-shots at the strawman) is inevitable. I think that the creative response is fostered by knowing about (at least the critical) constraints/ requirements/pro-and prescriptions. Also, midterm reviews would serve as a filter to improve the purity of products (ideas, engineering concepts) for NASA, as well as between the academic bodies.

B. I would like to see a typical USRA advanced space design program R.F.P. It seems like greater specification of topics and required subtopics (don't forget human factors/ habitability) would be useful. But again, this is only an observation from this meeting. Perhaps greater differentiation, too, between awardees' area of focus (e.g., breaking up parts of the Mars mission, rather than having so many schools taking on the whole realm). On the other hand, this is similiar to the practice of Design Competitions in architecture wherein the client stipulates the problem(s) and each competitor studies the problem(s) and actually enters conceptual and maybe preliminary design solutions/suggestions. Usually this is practiced only when the stakes are high, and thus it is an exciting process (although expensive for the competitors). Here, though, the schools are not competitors, and one semester is a fairly limited opportunity for such a complex problem set. I would limit the problem for short term projects.

C. I like the idea of *continuity* within the schools from year to year, and I wonder how well this is working. Will the students from this year give an orientation workshop for their successors? (They should.) Do they leave good road maps, e.g. reports, project schedules/memos/("corporate memory") ? Certainly we all have benefited from the brevity of the viewgraph summary, but typically these are not stand-alone explanations. For continuity there should be clear, descriptive documentation from one "generation" to the next. (Reports were not readily offered by the schools at the conference).

D. I would like to see maximal emphasis on the problem solving process and encouragement to the students to avoid jumping too quickly to solutions (that they feel committed to and must defend against critique). This is valuable for all of us, especially designers. Architects and social scientists working together have developed good predesign analysis procedures and these are beginning to show up in facilities.

PHYSIOLOGICAL
- Gravity
- Radiation
- Food & Nutrition
- Disease & Toxins
- Atmosphere and Control
- Waste management

PSYCHOLOGICAL
- Psychological health
- Communication with Earth
- Habitability
- Productivity and Creativity
- Multiple Jobs
- Deviant Behavior
- Quarantine and/or Isolation

SOCIOPOLITICAL
- Decision Making
- Crisis Management
- Personal Management
- Interpersonal Relations
- Training & Selection

ACCEPTABLE RISKS
- Radiation
- Redundancy for Life Support
- Multiple Exits
- How to Justify/Establish Requirements
  - Technical
  - Political

PROGRAM PROCESS WORKSHOP

E. Schwartz, NASA Headquarters
S. Lowy, Texas A&M

The following summarizes some key discussion points of the workshop. They are not intended to be conclusive but represent areas for further consideration by program participants.

I. SUMMER PROGRAM

- One university representative guaranteed a slot at NASA center; any additional slots available by competition, project merit
- Students selected for summer program should be prospective seniors (completed junior year) or prospective graduate students. Experience at center can then be of use when students participate in senior design course or act as T.A.'s the following fall semester.
- Students from non-grant universities who could attend a center during summer could be of assistance to the university in joining the program.

II. CENTER/UNIVERSITY INTERACTION

- NASA prohibition on use of grant money for travel makes it difficult for center personnel to visit universities (and university students to visit center).
- Seek funding from industry: supplemental funds to USRA (potential help with travel funding problem).

- Improvements in communication can occur through increased use of TELEMAIL, College Lectures in Aerospace Sciences (CLASS) program, Intergovernmental Personnel Act (IPA) assignments, college lecture programs, satellite networks, center literature searches
- General meeting between USRA personnel and professors in August might be desirable
- Produce a brochure to inform universities of program opportunities
- NASA should: supply more leadership re individual projects to enhance final product; encourage use of national studies; tweak projects to consider possible future commitments.
- For next national conference, schedule parallel presentation sessions, grouped by research topic, to allow more time for discussion, workshop interaction.

III. TECHNICAL REPORTS: Options

- USRA maintains library of complete reports and lends them to requestors
- Microfiche copies of complete reports distributed to all program participants
- Executive summary (20 pp.) of reports reproduced and distributed to all participants

IV. UNFUNDED INVOLVEMENT

- Unfunded or "alumni" schools may submit abstract of work relevant to the program; if accepted, travel may be funded by USRA for 1 or 2 students to make presentation at annual conference.
- School may be directed to other NASA programs or government agencies to seek funding.
- Link to other university programs: graduate student research projects, post-doc research

Conference Program

Tuesday, June 17
7:30–9:00 pm . . . . WELCOME RECEPTION
Holiday Inn, Cocoa Beach

Wednesday, June 18 Training Building
Kennedy Space Center

8:00 . . . . WELCOMING REMARKS
Dennis Mathews, Kennedy Space Center
Jack Sevier, USRA
Stan Sadin, NASA Headquarters

Summary Presentations

University Advanced Space Design Projects

8:15 A Lunar Transportation System . . . . AUBURN

8:45 Mars Rover . . . . CAL TECH

9:15 Lunar Fiberglass Production . . . . CLEMSON

9:45 . . . . Break

10:00 Geosynchronous Space Station . . . . COLORADO

10:30 Regenerative System for Growing Higher Plants . . . . FLORIDA

11:00 Lunar Mining Devices and Other Studies . . . . GEORGIA TECH

11:30 Lunar Oxygen Transportation System . . . . ILLINOIS

12:00 Mobile Remote Manipulator System . . . . MARYLAND

12:30 . . . . Lunch

1:30 Mars Exploration Missions . . . . MIT

2:00 Manned Mars Mission (Project Kepler) . . . . MICHIGAN

2:30 . . . . Break

2:45 . . . . Adjourn to Workshops

4:15 . . . . Reconvene in Plenary Session

4:15–5:15 . . . . Dr. Kathryn Sullivan

Wednesday Evening TRADITIONAL FLORIDA LUAU
Holiday Inn, Cocoa Beach
Cash Bar: 6:45 Meal Time: 7:45

Thursday, June 19 Training Building
Kennedy Space Center

8:00 . . . . Announcements

Summary Presentations

8:15 Space Stations & Transportation Systems . . . . . NAVAL ACADEMY

8:45 Manned Mars Mission . . . . NC STATE

9:15 Mars Surface-Based Factory . . . . PRAIRIE VIEW A&M

9:45 . . . . Break

10:00 Manned Mars Mission . . . . TEXAS A&M

10:30 Manned Mars Mission . . . . UT, AUSTIN

11:00 Launch/Landing Facility for Lunar Base . . . . TUSKEGEE

11:30 Advanced Lunar Survey System . . . . VPI

12:00 Multi-Megawatt Nuclear Power System . . . . WASHINGTON

12:30 . . . . Lunch

1:30 Mars Habitat . . . . WISCONSIN

2:00 Lunar Base . . . . HOUSTON

2:30 . . . . Break

2:45 . . . . Adjourn to Workshops

4:15 . . . . Reconvene in Plenary Session

4:15–5:15 . . . . NASA: Future Directions
Stan Sadin and TBD Others
NASA Headquarters

Thursday Evening . . . . FUTURE MISSIONS DISCUSSION
Led by Harrison H. Schmitt
Holiday Inn, Dolphin Room

Friday, June 20 Training Building
Kennedy Space Center

8:30 . . . . Announcements

8:45–11:30 . . . . Working Group Reports

11:30 . . . . Concluding Remarks

12:00 . . . . Lunch

2:00–4:45 . . . . Bus Tour of KSC

5:00 . . . . Buses return to motel

WORKSHOPS

Background: One of the original objectives of the NASA/University Advanced Space Design program was to identify major technology enhancements necessary to accomplish the missions envisioned for the post IOC Space Station era. Now that we are in the second year of the pilot program, there should be sufficient background to begin to identify what these technology drivers will be.

Accordingly, in the afternoon sessions on Wednesday and Thursday, we plan to focus on this objective.

Format: Nine groups, organized along the technology discipline lines listed below, will meet during the afternoon sessions to discuss the major problems to be solved in their areas of interest and the technology needed to arrive at solutions. Each group will be co-chaired by a NASA and a university representative. Other conference participants will join one of the nine groups that best suits their interests and expertise.

Conference participants will be given the opportunity to submit written questions to any of the working groups on relevant topics that they would like to see addressed.

A tenth group, Program Process, will meet at the same time to discuss the program itself and identify potential improvements that might be incorporated in the future.

Student participants are expected to ally themselves with the workshop group that best coincides with their area of interest; however, to ensure broadest participation, no more than one student per university per workshop is recommended.

Group leaders will be expected to summarize their discussions and recommendations in a wrap-up session on Friday morning and to submit a brief written report before the conference adjourns. The technology reports are expected to include (1) description of the technology needs for each class of mission, (2) a listing, in order of importance, of the key technology tasks to support the overall mission set, and (3) innovative research areas that offer a high payoff in the ability to accomplish the missions. Fruitful research areas identified could be a valuable source for doctoral and postdoctoral projects of interest to NASA and the universities. Groups are encouraged to think along lines of new ideas and new approaches rather than simple extrapolations of existing concepts.

Workshop Groups and Assignments

Space and Entry Environments
R. Kennedy, Johnson Space Center
Marv Luttges, U. of Colorado

Automation and Robotics
Jim Burke, Jet Propulsion Laboratory
F. Kulick, Cal Tech

Space Manufacturing
Wendell Mendell, Johnson Space Center
J. Nichols, Auburn University

Space Structures and Materials
J. Youngblood, Langley Research Center
H. Buning, U. of Michigan

Space Power
Lisa Kouhout, Lewis Research Center
A. Bruckner, U. of Washington

Information Systems/Communications/Data Requirements
S. Paddock, Goddard Spaceflight Center
W. E. McCracken, Naval Academy

Mission Planning
Barney Roberts, Johnson Space Center
W. Fowler, U. of Texas

Space Propulsion
Frank Swalley, Marshall Spaceflight Center
K. Sivier, U. of Illinois

Life Sciences/Human Factors/Life Support Systems
Y. Clearwater, Ames Research Center
G. Nevill, U. of Florida

Program Process
E. Schwartz, NASA Headquarters
Stan Lowy, Texas A.& M.

List of Attendees

Anwar Ahmed	Tuskegee	(205)727-8979
Loren A. Anderson	U. of Central Florida	(305)975-2155
A. E. Andreoli	California Polytechnic	(805)546-2666
Kenneth V. Arneson	U.S. Naval Academy	(301)286-8152
Matthew Ashley	U.S. Naval Academy	(301)794-6492
Roger Biasca	M.I.T	(209)838-2918
Patricia Boardman	U. of Florida	
James W. Brazell	Georgia Tech	(404)255-3688
James Brock	Auburn	(205)544-5039
Jeff Brown	U. of Houston	(713)643-0094
Adam P. Bruckner	U. of Washington	(206)543-6143
Harm Buning	U. of Michigan	(313)764-4310
J. D. Burke	NASA/Jet Propulsion Lab	(818)354-6363
Cara Carson	NASA Headquarters	(202)453-2704
Ann Chopra	U. of Michigan	(216)433-2404
Yvonne Clearwater	NASA/Ames Research Center	(415)694-5937
Ronald S. Clifton	U. of Illinois	(213)615-4308
Jerome Collins	Tuskegee	(205)727-8970
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